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THE FEASIBILITY OF HIGH PRESSURE OPERATION AND DETERMINATION OF THE OPTIMUM GAIN ZONE IN CHEMICAL OXYGEN-IODINE LASERS

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ABSTRACT Use is made of a simple model to theoretically prove that there exist optimum values for small signal gains in chemical oxygen-iodine lasers dependent on overall system oxygen pressures. At the same time, the feasibility of chemical oxygen- iodine laser operations under high pressure is discussed. Finally, methods for determining optimum gain zones for chemical oxygen-iodine lasers are given.

KEY WORDS Chemical oxygen iodine laser High pressure operation Optimum gain zone

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I. INTRODUCTION

Chemical oxygen-iodine lasers are a type of high efficiency, short wave length chemical laser with very good development prospects which have expanded in recent years [1]. According to reports, the U.S. has already realized continuous wave oxygen-iodine laser systems with output powers reaching 58kW [2]. They first of all go through chemical reactions to produce high concentration $O_2(^1\Delta g)$. After that, near resonance transmission energies cause iodine atom $5^2p_{1/2} \rightarrow 5^2p_{3/2}$ excitation emission reception, producing 1.315 micron near infrared laser outputs. The processes described above can be summarized as [3]

$$Cl_2 + H_2O_2 + 2NaOH \longrightarrow O_2(^1\Delta g) + 2NaCl + 2H_2O \quad (1)$$

$$n\ O_2(^1\Delta g) + I_2 \rightarrow n\ O_2(^3\Sigma g) + 2I(^2p_{3/2}),\ 3 \leqslant n \leqslant 5 \quad (2)$$

$$O_2(^1\Delta g) + I(^2p_{3/2}) \rightleftharpoons O_2(^3\Sigma g) + I(^2p_{1/2}) \quad (3)$$

$$I(^2p_{1/2}) + h\nu \longrightarrow I(^2p_{3/2}) + 2h\nu \quad ,(\lambda = 1.315\mu m) \quad (4)$$

Due to the high energy high efficiency characteristics of chemical oxygen-iodine lasers, as a result, there are people who have suggested opting for the use of oxygen-iodine laser systems to act as iodine laser oscillation amplification system amplifiers [4] in order to facilitate the production of adequately high energy lasers used in nuclear fusion research. However, up to the present time, reports have not yet been seen on oxygen-iodine systems which can be employed. At the present time, the main problem with opting for the use of oxygen-iodine systems lies in considering high pressure quenching problems associated with $O_2(^1\Delta g)$. Lasers are only capable of operating under low pressures (generally, around 133Pa). Moreover, from kinetic analysis of oxygen-iodine transmission energies as well as experimental results, it is possible to know that operating pressures associated with iodine generally do not reach higher than one one hundredth $O_2(^1\Delta g)$ pressures [5]. This clearly shows that $I(^2p_{1/2})$ acting as activation medium for chemical oxygen- iodine lasers is only capable of operating at low concentrations. This leads to chemical oxygen-iodine lasers being a type of low gain laser. Small signal gains are only around 10-4 - 10-3 /cm [6,7]. If one is thinking about increasing the operating performance of oxygen-iodine lasers, it is, first of all, necessary to determine the high pressure performance characteristics, that is, effectively raising $O_2(^1\Delta g)$ partial pressures. In order to achieve this objective, Basor and others have suggested making materials containing iodine with

photolytic types similar to CF3I act as iodine atom sources for oxygen- iodine lasers. In this way, it is possible to make ratio limits associated with I2O2 improve close to 10 fold [8]. Another area is nothing else than the development of O21G generators capable of operating under high pressures, correspondingly producing spray type [9] and hot wall type [10] O21G generators.

Recently, Endo and others have made use of revolving wheel type O21G generators to produce close to 4522Pa O21G , and, in conjunction with this, within as short a time as possible (on the order of several tens of ms), mixing with iodine molecules, successfully obtaining pulse oxygen-iodine laser output [5] associated with pure chemical pumps. From experiments, it was proven that high pressure chemical oxygen- iodine laser operations are feasible. /517

Below, we will make use of a simple model to discuss the relationships between oxygen-iodine laser gains and overall system oxygen pressures. Theoretically, it will be proven that there exist optimum chemical oxygen-iodine laser gain values which depend on overall system oxygen pressures. In conjunction with this, we will strive hard to explain the feasibility of chemical laser high pressure operation. Finally, methods for determining system optimum gain zones will be given.

2 OPTIMUM RELATIONSHIPS ASSOCIATED WITH CHEMICAL OXYGEN-IODINE LASER GAINS DEPENDENT ON OVERALL OXYGEN PRESSURES

In continuous wave chemical oxygen-iodine lasers, the iodine atoms which act as activation media, are produced by collision of O21G and iodine molecules and dissociation. The kinetic processes are described in equation (2). Due to the fact that, during actual operations, the ratio between amounts of O21G and amounts of iodine molecules introduced is more or less 100 [5], it is, therefore, possible to believe that, when iodine molecules are in the process of mixing with O21G , there is complete dissociation. Correspondingly, one has the relationship below [11]

$$[I(^2p_{3/2})]+[I(^2p_{1/2})]=2[I_2] \tag{5}$$

In this, [A] stands for the molar concentration of constituent A. From this, it is possible to obtain gains associated with chemical oxygen-iodine lasers as [1]

$$G=\sigma[I_2]\cdot\frac{2\alpha f-1}{\alpha f+1} \tag{6}$$

In this, σ is the cross section receiving stimulation emissions associated with $I(^2p_{1/2})$. f stands for the relative amount of O21G contained, that is, $f=[O_2(^1\Delta g)]/[O_2\ (^3\Sigma g)]$; . α

=0.75exp (402/T). When T=300K, σ and α are nearly respectively equal to 7.4x10-18 cm2 and 2.9[1]. If use is made of ■ to represent percentage content of O21G , then, one has

$$f=\eta/(1-\eta) \tag{7}$$

From equation (6), it is possible to see that, if one wants to raise oxygen-iodine laser gains, one type of feasible means is nothing else than increasing iodine molecule concentrations. However, due to activation media being obtained from collisions of O21G with iodine molecules and dissociation, as explained before, kinetic analysis and experimental results clearly show that there exist optimum composition ratios between O21G and iodine molecules. The values are approximately [1]

$$[O_2(^1\Delta g)]/[I_2]\approx 100 \tag{8}$$

If one uses k to represent optimum composition ratios associated with O21G and iodine molecules, one then has

$$[I_2]=\frac{1}{k}[O_2(^1\Delta g)] \tag{9}$$

This clearly shows that, if one wants to raise iodine molecule concentrations, one must, first of all, raise molar concentrations of O21G , that is, O21G partial pressures. If one uses pa to stand for O21G partial pressures, and, in conjunction with that, take the two equations (7) and (9) and substitute into (6), we can obtain the relationship equation for oxygen-iodine laser gains dependent on O21G partial pressures and percentage amounts of ■ contained

$$G=\frac{\sigma}{kRT}p_a\cdot\frac{2a+1-1/\eta}{a-1+1/\eta} \tag{10}$$

From the equation above, it is possible to know that, when investigations are respectively done on the influences of O21G partial pressures and percentage amounts contained on oxygen-iodine laser gains, increasing O21G partial pressures and percentage amounts contained, in both cases, is capable of increasing laser gains. Besides that, we know that, if p is used to stand for O2 pressure, then, pa can be expressed as

$$p_a=p\eta \tag{11}$$

Taking (11) and substituting into equation (10), then

$$G=\frac{\sigma}{kRT}p\eta\frac{2a+1-1/\eta}{a-1+1/\eta} \tag{12}$$

If the patterns of change in gas phase transmission associated with O21G are known, then, it is possible to carry out qualitative analysis on equation (12).

In chemical oxygen-iodine lasers, if consideration is given to simplified states, generally speaking, O21G gas phase transmission patterns can be expressed as [2]

$$1/\eta = 1/\eta_0 + \alpha p \tau \tag{13}$$

In this, ■o stands for the rate of O21G generation, that is, the percentage amounts of O21G produced by O21G generators. τ is the residual period associated with O21G in the gas phase. α is a constant which is approximately 89Pa1 ■ s-1 [1]. From equation (12) and equation (13), it is possible to see that raising system operating pressures, on the one hand, is capable of increasing O21G concentrations, that is, /518 O21G partial pressures, thereby raising laser gains. On the other hand, due to pressure increases, collision quenching associated with O12G is intensified, causing percentage amounts of O12G contained to develop in the direction of reduction--not advantageous to increasing laser gains. The results from the two combined effects lead to an optimum relationship existing between laser gains and overall oxygen pressures. Taking equation (13) and substituting into equation (12), we are able to obtain the relationship of gains depending on overall oxygen pressures p to be

$$G = \frac{\sigma\eta_0}{kRT} \cdot \frac{p}{1+\eta_0\alpha p\tau} \cdot \frac{2a+1-1/\eta_0-\alpha p\tau}{a-1+1/\eta_0+\alpha p\tau}$$

Solving for the partial derivative of gain G with regard to p

$$\frac{\partial G}{\partial p} = \frac{\sigma\eta_0}{kRT} \cdot \frac{1}{(1+\eta_0\alpha p\tau)^2(a-1+1/\eta_0+\alpha p\tau)^2} \cdot [-(3a\eta_0+1)(\alpha p\tau)^2 - 2(a-1+1/\eta_0)(\alpha pt)+(2a+1-1/\eta_0)(a-1+1/\eta_0)] \tag{15}$$

If use is made of Popt to stand for overall oxygen pressures making laser gains take maximum values, then, one has

$$\frac{\partial G}{\partial p}\Big|_{p=p_{\text{■}}} = 0 \tag{16}$$

As a result, from equation (15), it is possible to obtain

$$(3a\eta_0+1)(\alpha p_{opt}\tau)^2+2(a-1+1/\eta_0)(\alpha p_{opt}\tau)-(2a+1-1/\eta_0)(a-1+1/\eta_0)=0 \quad (17)$$

Letting $x=\alpha p_{opt}\tau$, equation (17) can change into the second degree equation relating to x

$$(3a\eta_0+1)x^2+2(a-1+1/\eta_0)-(2a+1-1/\eta_0)(a-1+1/\eta_0)=0 \quad (18)$$

The greater than zero solution of second order equation (18) is

$$x=[\sqrt{3a\eta_0(2a+1)(a-1+1/\eta_0)}-(a-1+1/\eta_0)]/(3a\eta_0+1) \quad (19)$$

In this, there is a requirement for

$$3a\eta_0(2a+1)>a-1+1/\eta_0 \quad (20)$$

that is, $$\eta_0>\frac{1}{2a+1}=(1+1.5\exp(402/T)) \quad (21)$$

The right side of equation (21) is just the lowest percentage amount of O21G content [13] needed to give rise to iodine atom reversal. This clearly shows that, so long as percentage amounts of O21G content are larger than the threshold value giving rise to iodine atom reversal, it is only then that discussions of chemical oxygen-iodine laser optimal gain problems have significance.

Since equation (18) has a larger than zero solution x, this clearly shows that, in chemical oxygen-iodine lasers, laser gains actually have optimal values dependent on system pressure changes.

3 DISCUSSION OF THE FEASIBILITY OF CHEMICAL OXYGEN-IODINE LASERS AS WELL AS DETERMINATION OF OPTIMUM GAIN ZONES

From the discussions above, it is possible to know that there exists an optimum relationship between chemical oxygen- iodine laser small signal gains and overall system oxygen pressures. That is, when $\alpha P\tau$ satisfies x solutions associated with (19), then, chemical oxygen-iodine laser small signal gains reach optimum values. If, when use is made of ■opt to stand for gains adopted at

optimum values, as far as oxygen-iodine mixture zone O21G percentage content amounts are concerned, from equation (13), it is possible to know that

$$1/\eta_{opt}=1/\eta_0+x \qquad (22)$$

Due to the fact that x is a variable quantity dependent on p and τ, it is solely determined by generator generation rates ■o . This clearly shows that, so long as generator generation rates ■o associated with O21G are determined, it is then possible to solve for x from equation (19). Going a step further, from equation (22), percentage O21G content amounts within mixing zones are determined when maximum laser gain values are adopted. When T = 300K and ■o = 1.00, from equation (19), one solves for x = 1.05 and ■o = 48.7%. This clearly shows that, when O21G percentage content amounts with mixture light output zones reach 48.7%, chemical oxygen-iodine laser gain systems reach maximum values. From this result, it is possible to see that there is no need to lower system operating pressures in order to maintain/519 high O21G concentrations. Fig.1 gives the relationships for ■opt dependent on ■o when T = 300K.

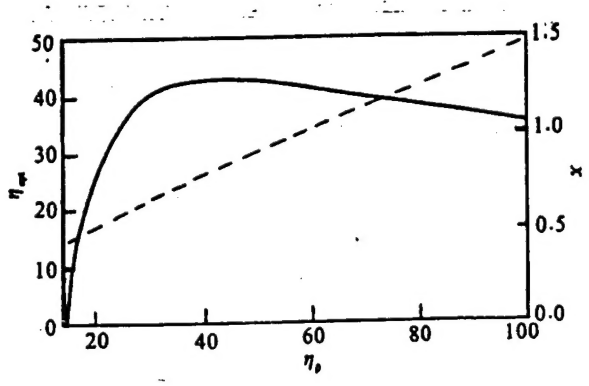

Fig. 1 Dashed line represent the relation of η_{opt} vs. η_0 solid line represent the relation of x vs. η_0

Due to the fact that x is a quantity which is determined solely by O21G generator generation efficiencies ■o , from the relationship form

$$\alpha\, p_{opt}\,\tau=x \qquad (23)$$

it is possible to obtain

$$p_{opt}=\frac{x}{\alpha}\cdot\frac{1}{\tau} \qquad (24)$$

Equation (24) clearly shows that, in cases where generator generation efficiencies are invariable, if the residual period in the gas phase for O21G is shortened, then, correspondingly, it is possible to increase overall oxygen operating pressures. This means nothing else than that the possibility of chemical oxygen-iodine laser operations under high pressures exists. Calculations are made below. Assuming that system temperature is T = 300K and O21G generator generation efficiency is ■o = 0.9, then, substituting x = 1.09 solved for from equation (19) into equation (24), one gets

$$p_{opt} = 1.65/\tau \qquad (25)$$

If one adopts τ = 300ms, then popt ≈ 733Pa. Moreover, from (22), it is possible to know that the O21G percentage amount contained within oxygen-iodine mixing zones is ■opt ≈ 45%. Then, the corresponding optimum O21G partial operating pressure is 333Pa. If one takes τ and shortens it to 30ms, then, popt is close to 7335Pa. Correspondlingly, there is a partial O21G pressure which is approximately 3333Pa. In the Endo experiments [5], oxygen-iodine mixture operating periods were only 50ms. Moreover, optimum experimental light output estimates were in roughly 30ms. In this type of situation, going through the calculations above, the partial pressure estimate for O21G in optical cavities is 3333Pa. This is basically in agreement with the experimental results obtained by Endo and others [14].

Since, in oxygen-iodine lasers, there exists an optimum gain zone dependent on overall oxygen operating pressure, as a result, through experimental determination of the locations of optimum oxygen-iodine mixing zones, this is very significant for raising laser operating performance. We will give a possible type of method for precisely determining optimum gain zones. Since percentage O21G amounts contained within optimum gain zones satisfy the relationships in equation (22), after oxygen-iodine mixing zone and optical cavity locations are precisely determined, if measurements are done of O21G generator generation efficiencies ■o , then, from equation (22), precise determinations are made of ■opt . In conjunction with this, going through alterations in system pressures, oxygen-iodine mixing zones, that is, percentage amounts of O21G contained within gain zones, are made to reach ■opt . This is nothing else than the location of optical cavities, that is, optimum gain zones for chemical oxygen-iodine lasers.

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